Research Article

Fulfilling Domestic Water Demand in Semi-arid Regions of North Karnataka: Challenges and Way Forward

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Abstract

The 2030 Agenda for Sustainable Development includes Goal 6 (SDG 6): 'Ensure availability and sustainable management of water and sanitation for all'. SDG target 6.1 aims to achieve by 2030 'universal and equitable access to safe and affordable drinking water for all'. The Government of India has also launched the Jal Jeevan Mission (JJM) to provide potable tap water to every rural household by 2024. In this context, this article explains the findings of a study to assess the domestic water demand and the availability of water in seven villages in the Ballari and Raichur districts in North Karnataka. This study indicates that groundwater is predominantly used for domestic purposes in these districts due to the lack of adequate and reliable surface water. Only 14% of households in the study area receive adequate water as per the JJM norms and this water stress is projected to worsen due to the increasing supply–demand mismatch in the future. The authors recommend the implementation of the revised configuration of the Krishna (Almatti)–Pennar river interlinking project by 2030 since this alignment is optimised to reduce project-related deforestation, people displacement, project duration and costs. This is critical for the sustainable development of North Karnataka.

Keywords

Drinking water, Jal Jeevan Mission, river interlinking project, sustainable development, SDG 6

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Introduction

A '*water-stressed country*' is one where demand for freshwater surpasses supply due to various factors (Kuzma et al. 2022). As per the World Health Organization (WHO 2019), 2.1 billion people (i.e., 29% of the world's total population) live in water-stressed countries, of which 785 million reside in rural regions. According to WHO (2019), 7 out of 10 individuals lacking basic amenities, such as access to drinking water, sanitation and handwashing (WASH) facilities, live in rural areas. A functional rural water supply system to provide domestic water supply and water for irrigation contributes to an increase in livelihoods and poverty eradication (Gazzinelli et al. 1998). However, due to the impacts of climate change, growing needs for socio-economic development, and increasing energy needs, water scarcity may worsen in many developing countries in the future (Mishra et al. 2021). Water scarcity may affect approximately 57% of the projected global population by 2050 (UN 2018). Considering the importance of water in ensuring socio-economic development, Sustainable Development Goal (SDG) target 6.1 emphasises the provision of '*universal and equitable access to safe and affordable drinking water for all'* by 2030 (UN 2015).

Water scarcity in the arid and semi-arid regions of India significantly impacts the quality of life of the rural population by affecting their livelihood and the overall socio-economic conditions (Nyong and Kanaroglou 1999; UN 2007). Further, climate change and the spatiotemporal variability of rainfall patterns are also expected to cause regional differences in water resources, potentially leading to more floods and droughts (Sheffield and Wood 2008).

In India, groundwater accounts for about 90% of the domestic water supply in rural areas and about 50% in urban areas since the built-up surface area in the urban environment deters groundwater recharging due to low rainfall infiltration (GEC 2015). However, in many rural settings in India, poor water demand management is largely attributable to a lack of efficient water distribution infrastructure, accompanied by the paucity of efficient governance and institutional arrangements (Damhaug 1996).

As per the WHO recommendations, the minimum per capita water supply only for domestic use in rural areas is 55 litres per day, which is also the norm fixed by the Ministry of Jal Shakti (MoJS), Government of India (GOI) (Chaudhuri et al. 2020; JJM 2021). While India's rural population requires about 22 billion cubic metres (BCM) of water per year to meet domestic and agricultural requirements, a large fraction of this population is unable to meet even their domestic water requirements today (Kumar et al. 2022). Against a global benchmark of 1,700 m^3 of fresh water availability per capita per year, the annual water availability per capita in India was projected to be only 1,368 m^3 in 2019 (MoJS, 2019; Rout and Kattumuri 2022). However, no comparable data are available on the domestic water availability in India. This is one of the reasons for conducting field surveys during this study. Moreover, for a diverse country like India, it becomes imperative to compute the deficit or surplus in the availability of water supply while keeping in mind the country's heterogeneity in terms of allocations of resources (Mishra et al. 2021; Nyong and Kanaroglou, 1999). Therefore, a proper understanding of water resource dynamics at the regional scale is essential to attain water security and greater resilience to hydrological extremes (Aju et al. 2021; Sheffield et al. 2018). Access to the public water supply through a tap connection is crucial to improve the quality of life for rural communities, particularly women and girl children, who spend a considerable amount of time each day fetching water from distant sources in developing countries like India (Gopaldas and Gujral 1995; JJM 2021).

While India's rural water supply framework has evolved over the years through the implementation of various government schemes, the continuing need for water security has prompted the GOI to launch the Jal Jeevan Mission (JJM) in 2019 (JJM 2019). The key objective of this mission is to provide safe and sufficient drinking water to every rural inhabitant through a functional household tap connection (FHTC) by 2024. As per JJM (2023), only 131.7 million of the 192.3 million rural households in India have a tap water connection. Therefore, more than 60 million rural households are still unable to receive drinking water through taps in India. Even if taps are provided, the availability of adequate water to supply the requisite amount of water to all rural households as per the JJM norms (55 litres per capita per day (lpcd)) will continue to be a challenge if there are no major water sector reforms in India. These reforms include building and upgrading water supply infrastructure, including pipelines, ponds, tanks and water treatment plants, to ensure efficient and reliable tap water delivery to rural households with commensurate capital investments.

Specific details of the water consumption pattern in semi-arid regions are essential to optimise the available water resources. Therefore, the authors conducted field surveys covering 701 households to study the patterns of domestic water consumption in seven villages in the districts of Ballari and Raichur in North Karnataka. In addition, secondary data sources on precipitation and groundwater levels were also analysed to assess the long-term patterns and changes in these districts.

Study Area, Data and Methods

Study Area

The study area is located within the Raichur and Ballari districts in the Kalyana–Karnataka (K–K) region and falls in the Northern Dry Zone and the North Eastern Dry Zone (Figure 1).

Historically, the K–K region is backward on most socio-economic indicators compared to the southern part of the state of Karnataka, leading to a substantial regional imbalance in the state (Aziz and Hanagodimath 2010). A committee headed by Dr Nanjundappa was formed by the Government of Karnataka (GOK) in 2000 to submit a report on the regional imbalances in the state and recommend the policies required to address them (Aziz and Hanagodimath 2010). According to this report, the Comprehensive Composite Development Index of four taluks (Lingsugur, Manvi, Deodurga, Sindhnur) in the Raichur district and three taluks (Sandur, Kudligi, Harapanahalli) in the Ballari district place them in the category

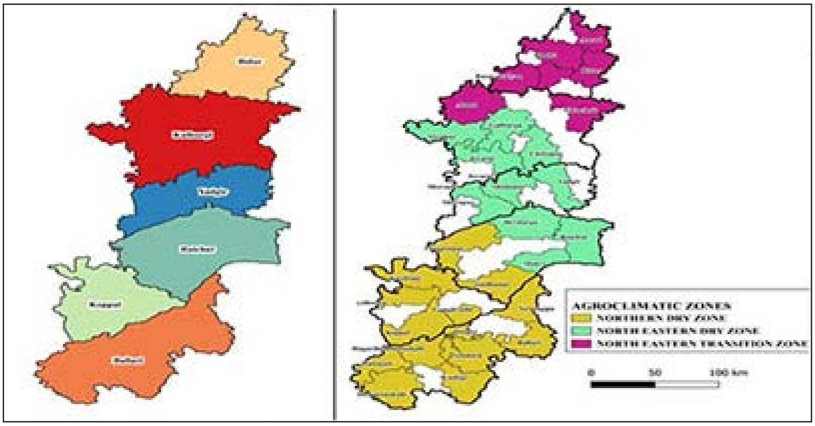

Figure 1. Districts and Agroclimatic Zones in the Kalyana–Karnataka Region.
Source: E-Krishi 2022.

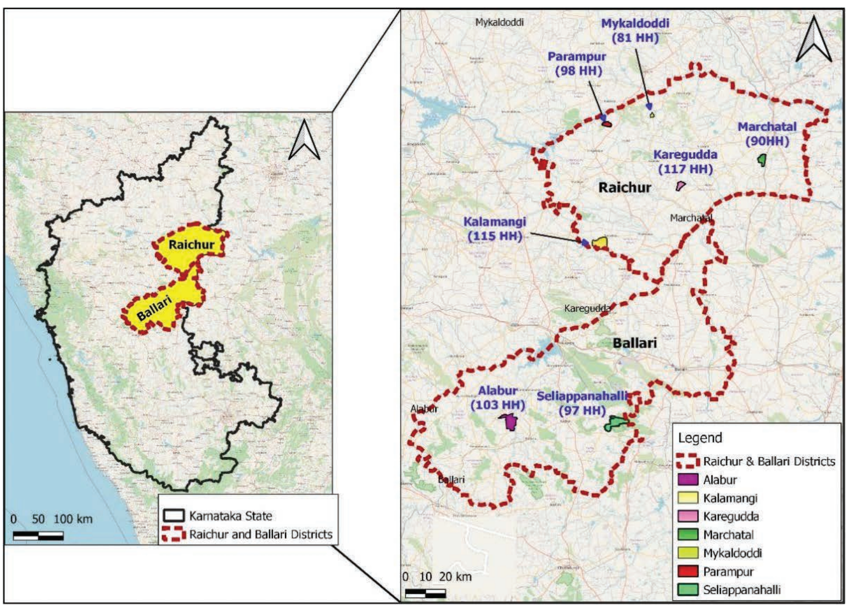

Figure 2. Map Showing the Villages Surveyed in the Study Area.

of the most backward taluks in the state. Water stress is one of the major reasons for the backwardness of these taluks, which is mainly due to the variability in the rainfall pattern in these districts.

Therefore, seven villages were selected from the six most backward taluks in the Raichur and Ballari districts for detailed field surveys to evaluate the water consumption patterns and access to drinking water at the household level, which are key indicators of socio-economic development (Hanagodimath 2014). The

Table 1. Village Profile in the Study Area.

Profiles	Kalamangi	Marchatal	Karegudda	Mykal-doddi	Parampur	Alabur	Seliappa-nahalli
Area (Ha)	3,415	1,513	1,047	315	946	3,977	4,099
Sched-uled Caste (SC)	329	429	293	507	925	658	1,026
Sched-uled Tribe (ST)	472	195	694	114	340	189	1,061
General category	1,643	1,333	613	485	188	2,615	310
Total popula-tion	2,444	1,957	1,600	1,106	1,453	3,462	2,397
Total number of house-holds	489	364	343	230	213	702	441
House-holds with tap connec-tion	752 (99%)	636 (100%)	1,297 (100%)	290 (100%)	0 (0%)	0 (0%)	0 (0%)
Jal Jeevan Mission (JJM) status	Ongoing	Com-pleted	Completed	Com-pleted	To be started	To be started	To be started

Source: Census 2011; JJM 2023.

villages surveyed in the Raichur district are Kalamangi, Mykaldoddi, Marchatal, Karegudda and Parampur, while the Alabur and Seliappanahalli villages were surveyed in the Ballari district (Figure 2). The majority of the population in these villages belong to Scheduled Castes and/or Scheduled Tribes (SC/ST) as shown in Table 1.

As stated by MoJS (2019), one of the goals of the JJM is to 'ensure that every rural household has a FHTC delivering water in adequate quantity (minimum 55 lpcd) of prescribed quality'. To assess the criticality of implementing the JJM to achieve SDG target 6.1 in the study area, the seven villages were selected in such a way that four villages have FHTC facilities while three villages do not have FHTC facilities (JJM 2023). As shown in Table A1 in the supplementary material, only the villagers living in Marchatal and Parampur in the Raichur district use surface water from ponds or canals in combination with groundwater sources, while the other five villages rely solely on groundwater from deep tube wells or open wells.

Table 2. Water Budgets for the Ballari and Raichur Districts in 2015.

	Raichur	Ballari
Total demand (BCM)	6.17	2.43
Total availability (BCM)	4.36	1.39
Deficit (BCM)	1.81	1.04

Source: PMKSY 2016a, 2016b.

Water Supply and Demand in the Raichur and Ballari Districts

The total demand and availability of water and the resulting gap in 2015 are shown in Table 2 (PMKSY 2016a, 2016b). As shown in Table 2, both the districts in the study area suffer from a water deficit, which will continue to increase due to population growth in these districts unless infrastructure and other interventions are implemented under the JJM to enhance water availability. The total demand including domestic, irrigation, power generation and other uses of water in the Ballari district in 2015 was estimated to be 2.43 BCM, while the combined availability from ground and surface water sources was estimated to be only 1.39 BCM, resulting the deficit of 1.04 BCM. Similarly, the total demand, availability and deficit figures for Raichur are estimated to be 6.17, 4.36 and 1.81 BCM, respectively (Table 2).

Variability in the Rainfall Pattern

Since five of the seven villages in the study area rely largely on groundwater to meet their domestic water needs, the rainfall data related to the Raichur and Ballari districts during the 1901–2019 period was collected from the India Meteorological Department (IMD) to study the extreme events in the study area and identify the surplus and deficit years based on IMD's Drought Manual using Equation (1) (IMD 2021).

$$DRF\% = \frac{(x-y)}{y} \times 100 \tag{1}$$

where x is the actual rainfall and y is the normal rainfall.

The long-term annual average rainfall in the Raichur and Ballari districts is 679 and 631 mm, respectively (IMD 2021). As shown in Figure 3, during the last 120 years, Raichur district recorded deficit rainfall for 45 years and excess rainfall in 13 of these 120 years. Ballari district experienced deficit rainfall for 38 of the 120 years and recorded excess rainfall only for 12 years (IWRIS 2021). Therefore, hydroclimatic extremes resulting in agricultural droughts characterised by a loss in agricultural productivity caused by unpredictable rainfall, rising temperatures and other variables that lower soil moisture are prominent in these two districts.

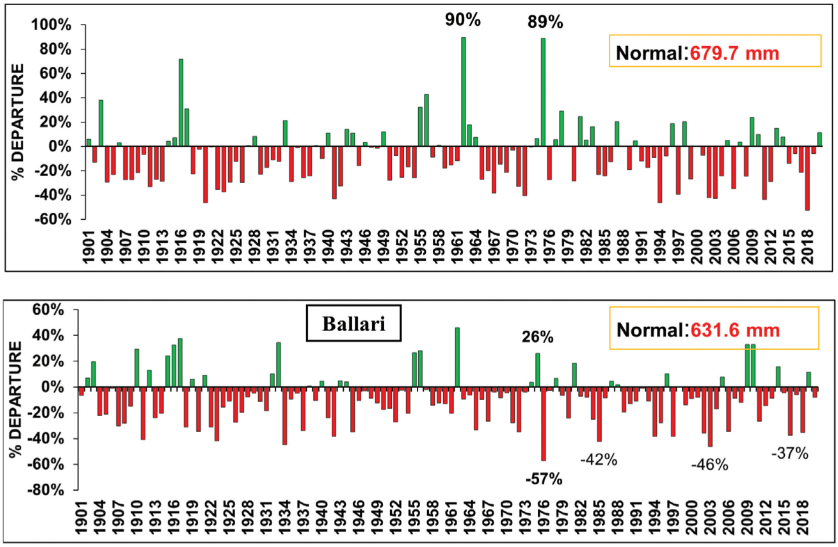

Figure 3. Departure of Annual Rainfall from Long-term Normal in the Raichur and Ballari Districts between 1901 and 2019.

Source: IWRIS 2021.

Groundwater Scenario in the Raichur and Ballari Districts

The major domestic water sources in the seven villages surveyed during the present study include groundwater (deep tube wells) and surface water (rivers, streams and canals) (Table A1 in the supplementary material). The groundwater level data (1995–2019) collected from the India Water Resources Information System (IWRIS) portal was analysed along with the rainfall data collected from IMD to understand the rainfall pattern and its relationship with the groundwater level in the study area (IMD 2021; IWRIS 2021).

The minimum and maximum groundwater levels (metres below ground level or mbgl) observed in the Raichur and Ballari districts are min: 3.8, max: 9.4 and min: 4.4, max: 13.6, respectively. As shown in Figure A1 in the supplementary material, groundwater levels in the succeeding year are becoming deeper with a decrease in rainfall in the preceding year.

The surveyed villages in the downstream areas of the canals could secure domestic water only from groundwater sources since they received insufficient surface water supply. Our field survey confirms earlier studies, indicating that regions within a network of concrete-lined canals downstream of storage reservoirs get less water (Ray and Isha 2011). Therefore, there is a need to increase the accessibility of surface water in the water-stressed districts of Ballari and Raichur. As shown in Table A2 in the supplementary material, from 2011 to 2020, an increase in net groundwater draft was recorded in both districts due to the cumulative effect of factors like inadequate surface water availability and population growth.

Methodology

A mixed-methods approach, including quantitative and qualitative methods based on primary and secondary data as well as field surveys, is used in this research. As this study is focused on aspects related to domestic water supply and demand in rural areas, the stratified random sampling method based on landholding size is applied to select the sample size. Therefore, a list of farmers was obtained from both the village administration and the revenue officer in charge of the village before the commencement of this field survey. All farmers in the list were then grouped by landholding size into five groups, viz., marginal farmers (owning less than 1 Ha), small farmers (owning between 1 and 2 Ha), semi-medium farmers (owning between 2 and 4 Ha), medium farmers (owning between 4 and 10 Ha), and large farmers (owning more than 10 Ha).

The selection of the sample population for the primary field survey was based on the decennial census data last collected in 2011. The number of households surveyed in each village was calculated using Equation (2).

$$H_{i,b,d} = \frac{\text{No. of households to be surveyed in Raichur / Ballari} \times \Sigma_i H_{i,b,d}}{\Sigma_d \Sigma_b H_i} \qquad (2)$$

where H_i, b, d is the number of households to be surveyed in village i in taluk b and district d.

In the Raichur district, one village was selected from each of the five taluks. The village selection was based on the proximity of the village's population to the average village-wise population of the district and the number of households primarily engaged in cultivation. In the Ballari district, only two villages could be surveyed due to the government and local restrictions imposed by the first two waves of the COVID-19 pandemic in 2020 and 2021.

The total sample size for the field survey in five villages of the Raichur district was 501, while the total sample size for two villages in the Ballari district was 200. Once the villages were selected for the field survey, we obtained the list of cultivators from the respective village revenue departments of villages. Subsequently, the number of households to be surveyed was stratified based on landholding size and selected proportionately from each of the five strata according to Equation (2). Our stratification strategy was based on landholding size, and we did not include landless households in the villages due to the non-availability of reliable data from the village officials. To this extent, our survey may have a slight positive bias since the landless households may have lesser access to domestic water supply compared to cultivators with landholdings.

A detailed questionnaire was prepared to collect the details relating to domestic water consumption (drinking, bathing, cooking, cleaning and others) and sources of water for domestic purposes. The total household water consumption was calculated based on the aggregate amount of water consumed by the 701 respondent households for drinking, bathing, cooking and washing use and converted to average daily per capita water consumption. The format of the questionnaire is shown in Tables A3 and A4 in the supplementary material.

Analysis of Variance (ANOVA)

A one-way ANOVA study was conducted to determine the influence of key socio-economic factors such as the average size of landholding, and the gender, social category, and literacy status of the head of household (HoH) on the per capita domestic water consumption in the seven villages studied. The details of the factors are shown in Table A5 in the supplementary material.

Stepwise Multiple Regression Analysis

A stepwise multiple regression analysis was performed to develop a model using per capita household water consumption as the dependent variable and other key parameters studied during the survey as independent variables (Table A5 in the supplementary material). The ordinary least squares (OLS) regression approach was used, and dummy variables were established for all of the categorical variables to evaluate the significance of the relationship(s) between the independent and dependent variables.

Future Projections of Water Demand in the Rural Areas of Raichur and Ballari Districts

Population forecasts reflect the projected population in the future based on a set of assumptions. They can assist in forecasting future water needs, which are directly linked to population growth. In this study, the authors used the decadal population data (1981–2011) of the rural areas of the Ballari and Raichur districts retrieved from the district census handbooks (Census of India 2019a, 2019b). The incremental increase method (IIM) is used to arrive at the population projections. This method considers both the average decadal numerical change and the increases in decadal numerical change across the decades of interest. The population growth in this method is self-balancing. A steep growth is seen if the decadal change increment is positive. On the other hand, the anticipated growth trajectory has a less steep profile when the decadal change is negative (MoUD 1999; Smith et al. 2013). The formula used in this method is shown in Equation (3).

$$P_n = P + n.X + \left\{\frac{n(n+1)}{2}\right\} \times Y \tag{3}$$

where P_n = population after the n^{th} decade, X = average increase, Y = incremental increase.

Results and Discussions

Sources of Water for Domestic Consumption

Currently, 74% of the rural households in Raichur and 65% of the rural households in Ballari have tap water connections (JJM 2023). Further, except in the Marchatal and Parampur villages, which had access to surface water, all other villages depend on groundwater sources (Table A1 in the supplementary material). The respondents were also questioned about the adjustments they made to their water consumption during periods of shortage to understand the coping measures undertaken by them in such circumstances. The respondents stated that shortages in water supply, which are prevalent during summer, prompt them to reduce water-intensive activities (cleaning or washing) to conserve water for primary purposes such as drinking and cooking. An evaluation of the availability of surface and groundwater resources across different districts and states should be undertaken by the government to ensure optimal planning and utilisation, as well as alleviate the gap in meeting the demand for domestic water consumption.

Volume of Water Consumed (Activity-wise)

For better water supply and demand management, policymakers and rural water delivery agencies must identify domestic water consumption needs and their end uses (Singh and Turkiya 2013). The WHO categorises the availability and accessibility of water for households into four categories, including the following (WHO 1997):

1. No access (having an average water consumption of less than 5 lpcd),
2. Basic access (20 lpcd on average),
3. Intermediate access (50 lpcd on average) and
4. Optimal access (100–200 lpcd on average).

To estimate the per capita water consumption, data on water use for various activities, including drinking, bathing, cleaning, cooking and other water-related activities, were also collected during the survey. This strategy assists in addressing the water issue in rural areas where it is challenging to gather such data (Roshan and Kumar 2020).

As shown in Table 3, the average amount of water used by the survey respondents for domestic purposes houses varied from a low of 34 lpcd in Parampur to a high of 48 lpcd in Kalamangi, with an overall average of 40 lpcd amongst the 701 households surveyed. Therefore, all the villages surveyed in the study area had only basic access to domestic water supplies as per the WHO (1997) norms. Additionally, only 14% of the households in the seven surveyed villages could avail domestic water supplies meeting the JJM-recommended standard level of 55 lpcd (Figure 4a).

Water Quality Perception

Detailed water quality analysis is out of the scope of the present study. However, water quality based on people's perceptions was included in the study. According to the respondents' assessments, about 75% of the households had access to sweet water, which may indicate that most of the tap water in the investigated villages is safe according to the quality standards of taste and colour (Figure 4b). However,

Table 3. Activity-wise Household Consumption Pattern in the Seven Villages Surveyed.

Activity	Water Consumption (in %) Drinking	Cooking	Bathing/ Cleaning	Other Uses	Total	Average Consumption (lpcd)
Kalamangi	6	6	86	1	100	48
Marchatal	8	7	74	11	100	39
Karegudda	8	7	74	11	100	38
Mykaldoddi	6	6	80	8	100	39
Parampur	12	13	69	6	100	34
Alabur	5	5	79	11	100	40
Seliappana-halli	4	5	83	8	100	43
Study average	7	7	78	8	100	40

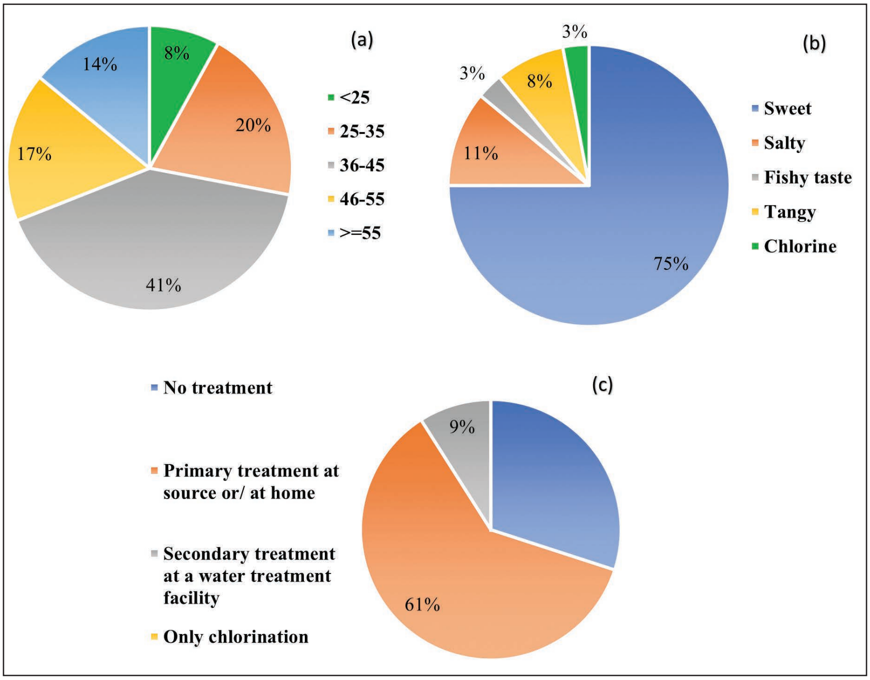

Figure 4. (a) Daily Water Consumption Pattern in the Surveyed Villages in Ballari and Raichur Districts (Litres/Day); (b) Perception of Water Quality Reported by the Respondents; (c) Accessibility of Water Treatment Facilities.

the responses of the householders revealed that increased fertiliser use is suspected to be the main reason for the decline in groundwater quality. This issue was raised by 69 households (14% of respondents) in the Kalamangi village where the cultivators make extensive use of fertilisers in their farms.

Table 4. Analysis of Variance (ANOVA) Table of Water Consumption across Different Social Categories.

Source	Number of Groups	Degrees of Freedom: Between the Groups	Degrees of Freedom: Within the Groups	*F* Value	*p* Value
Gender of HoH	2	1	699	3.15	0.076
Social category of HoH	3	2	698	1.0	0.396
Literacy status of HoH	4	3	697	1.12	0.340
Tap connections (JJM)	2	1	699	16.91	0.000

Note: HoH, head of household; JJM, Jal Jeevan Mission.

In contrast, other tastes such as salty, fishy, tangy and chlorine were reported by 25% of the total surveyed households. With reference to the availability of water treatment facilities in the study area, the authors found that out of 701 households surveyed, 30% used untreated water and 61% used treated water at home. The balance 9% of the survey respondents used water supplied by the government after secondary treatment (Figure 4c).

Variation in Household Water Consumption across Socio-economic Parameters

The ANOVA technique is utilised to compare the means of different independent variables to assess if there exist any statistically significant differences between them (Sirkin 2006). This technique is used in this study to test the influence of the categorical variables (gender of the HoH, social category of the HoH, tap connection (with/without) and the literacy of the HoH) on the per capita household water consumption. The results are summarised in Table 4.

As shown in Table 4, the social category and literacy status of the HoH do not have a statistically significant impact on per capita domestic water consumption in the study area. While the gender of the HoH does not have a statistically significant impact on the per capita domestic water consumption levels at the 95% confidence level, it has a statistically significant impact at a confidence level of 90%. The average per capita water consumption of a household headed by a man was observed to be 42 lpcd while that headed by a woman was slightly higher at 45 lpcd. The provision of tap connections under the JJM has a statistically significant impact on the per capita domestic water consumption levels in this study. Analysis of the data collected during the field survey indicates that, on average, the respondents living in a village without tap connections (n = 298) receive 12% less water than those in a village with a tap connection (n = 403) as per JJM. Therefore, the implementation of the JJM in all villages is necessary to achieve SDG 6.1 (Safe and Affordable Drinking Water) in rural areas of India.

The forward selection method in the Minitab (2023) software package was used to perform stepwise multiple linear regression (SMLR) analysis on the data collected during the field survey to quantify the relationships between independent variables and the per capita domestic water consumption of the 701 households surveyed (lpcd). The forward selection method adds one variable in each step as long as all variables not in the model have *p* values greater than the specific alpha (0.05 in our study) to enter. As shown in the results summarised in Table 5, the final SMLR model developed in this study retained only three independent variables as shown in Equation (4):

$$\begin{aligned}&\text{Water consumption per capita per day} = 56.19 + 0.30\\&\times \text{Household landholding} - 3.33 \times \text{Household size (HS)}\\&+0.0 \times \text{Tap connection (No)} + 8.43 \times \text{Tap connection (Yes)}\end{aligned} \tag{4}$$

As shown in Table 5, the SMLR model is highly significant with an *F*-statistic of 76.18.

As shown in Table 5, the SMLR model has a standard error of 14.93, indicating the average amount by which our predictions of the per capita domestic water consumption for a particular household might deviate from the actual value. Additionally, the adjusted *R*-squared value of 0.24 suggests that approximately 24% of the variation in per capita domestic water consumption in the study area can be explained by our model (Table 5).

Projections of Future Domestic Water Demand

Using low- or medium-variant population predictions is conventional when estimating water demand. This is because an ‘upper bound demand estimate’ would result in significant additional capital expenditures (Rinaudo 2015). Based on the survey data for the selected villages, the current domestic water consumption patterns are developed for the rural areas of the two districts. As per the 2011 census, the total rural population of the Ballari and Raichur districts is estimated to be approximately 2.97 million, which is projected to increase to about 4.25 million in 2050 (Census of India 2019a, 2019b; MoJS 2019). The projected population for 2050 is then used to estimate the domestic water demand for 2050 based on the per capita water supply rate of 55 lpcd for rural areas as per MoJS norms (MoJS 2019).

As per these estimates, the total domestic water demand in the rural areas of the Raichur and Ballari districts is estimated to reach 86 Mm^3 by 2050 (Figure A2 in the supplementary material and Table 6). However, the annual domestic water availability in the rural areas of the Raichur and Ballari districts is only 49 Mm^3 today since the average domestic water supply to the households is constrained at the level of approximately 40 lpcd as per the field survey due to the short supply of water. Therefore, the people living in these areas will face a huge shortfall in domestic water supply in the next 30 years unless the government enhances water

Table 5. Summary Output of Multiple Linear Regression Analysis.

Regression Statistics						
Multiple *R*	0.50					
R-squared	0.25					
Adjusted *R*-squared	0.24					
Standard error	14.93					
Observations	701					
Analysis of Variance (ANOVA)						
	df	SS	MS	*F*	Significance *F*	
Regression	3	50,942.22	16,980.74	76.18	1.26262E-42	
Residual	697	155,368.25	222.91			
Total	700	206,310.47				
	Coefficients	Standard Error	*t* Stat	*p* Value	Lower 95%	Upper 95%
Intercept	56.19	1.63	34.5	4.8019E-153	52.99	59.38
Household landholding	0.30	0.11	2.8	0.004925721	0.09	0.51
Household size	–3.33	0.24	–14.1	4.12911E-40	–3.80	–2.87
Tap connection (JJM)	8.45	1.16	7.3	1.05691E-12	6.16	10.74

availability through a major water supply project and the existing domestic water supply infrastructure (including treatment facilities) is also strengthened to supply the requisite volume of household water.

Measures to Strengthen Water Security in the Study Area

Globally, policies are designed either to reduce water consumption, referred to as 'demand-side strategies', or enhance freshwater availability, referred to as 'supply-side strategies', to manage existing and expected future water strains (Katz 2016). The Tungabhadra (TB) reservoir with a gross storage capacity of

Table 6. Water Demand Projections in the Rural Areas of Raichur and Ballari Districts.

Year	Raichur District (Mm^3)		Ballari District (Mm^3)	
	@40 lpcd (Actual)	@55 lpcd (JJM Norm)	@40 lpcd (Actual)	@55 lpcd (JJM Norm)
2021	24	33	25	35
2030	26	36	27	38
2040	29	40	29	40
2050	32	44	30	42
2060	34	47	31	43

3,742 Mm^3 was completed in 1953 as an inter-state project to serve some of the drought-affected areas in Karnataka and Andhra Pradesh. The Tungabhadra Left Bank Canal serves the Raichur district, while the Right Bank High Level Canal serves the Ballari district. However, as shown in Figure A3 in the supplementary material, there is a decrease of 24% in the reservoir's storage capacity from 3,718 to 2,856 Mm^3 between 1953 and 2008 due to siltation in the reservoir. This has affected this reservoir's capability to supply the desired amount of water to its command area, which also includes the study area districts of Ballari and Raichur (TB Board 2020).

In such areas, inter-basin water transfer (IBWT) is one of the most effective means to alleviate water shortage and improve surface water (Jain et al. 2008). It minimises the flood and drought risks as the water moves from surplus to deficit basins via engineered infrastructures. However, several studies have highlighted the diverse implications of such projects on the environment, society and governance (Gupta and van der Zaag 2008). The Almatti–Pennar Interlinking of Rivers (A–P ILR) project proposed by the National Water Development Agency (NWDA) is one of the components of the Peninsular Rivers Development Component of the National Perspective Plan (NWDA 2005). According to the rainfall-runoff regression model (@75% dependency), 1,980 Mm^3 of Krishna water can be utilised for en-route irrigation in the Krishna and Pennar basins in exchange for the excess Godavari water transferred to the Krishna basin after the completion of the ongoing Polavaram project (NWDA 2005). After meeting the domestic water needs in the command area, which includes a major part of the drought-affected Raichur and Ballari districts, 372 Mm^3 of water has been allocated from this project to irrigate 82,000 Ha in these two districts (NWDA 2005).

In its feasibility report for the A–P ILR project, NWDA (2005) has proposed a 587-long gravity canal with a balancing reservoir at Kalvapalli across the river Pennar in the Ananthapuramu district of Andhra Pradesh with a gross storage of 83 Mm^3. The construction of this reservoir will submerge an area of approximately 1,323 Ha and also result in people displacement that is best avoided. The authors of this article have used geospatial techniques and multi-criteria decision-making (MCDM) methods to develop an optimal configuration for this project that will utilise the existing reservoirs in place of constructing a new Kalvapalli reservoir (Ahmed and Srikanth 2023). The optimal A–P ILR project configuration proposed by the authors in an earlier study will reduce the cost, environmental impact and people displacement related to this project by eliminating a new reservoir and reducing the canal length by 200 km (Figure A4 in the supplementary material). The NWDA has also endorsed the methodology adopted by the authors of this article to determine the optimal A–P ILR alignment in the 17th meeting of the 'Task Force for Interlinking of Rivers' held on 6.3.2023 in Hyderabad (NWDA 2023).

Other Approaches and Infrastructure for Sustainable Water Management

According to our survey, most households in the study area depend on groundwater for domestic water supplies. Hence, creating additional water harvesting infrastructure like tanks is necessary to manage the study area's water resources. The demand placed on groundwater irrigation could also be lessened by building tanks where they are appropriate, particularly in locations with close proximity to surface water sources. These tanks can be connected to branch canals from the proposed A–P ILR project to provide vital water services like aquifer recharge, water storage during summers, drought prevention and a clean and adequate water supply. The Integrated Water Resources Management (IWRM) approach is a sustainable means for water management to incorporate the multiple competing uses of water resources to overcome looming water shortages and conflicts (Goyal et al. 2020).

Summary and Conclusions

Due to the ongoing water deficit caused by erratic rainfall patterns, securing enough water even to meet domestic water consumption needs is challenging in the drought-prone regions of Ballari and Raichur districts even during the non-drought years. Similarly, considerable disparities exist in the availability of major and minor irrigation sources and infrastructures between the upstream and downstream taluks on the TB canal systems. The field survey also highlights the fact that groundwater is the primary source of domestic water in all the study villages due to the lack of adequate access to surface water. Further, three of the seven surveyed villages rely solely on groundwater, even for irrigation, due to the lack of surface water infrastructure.

Although the field survey was conducted during a normal rainfall year, it was found that the average per capita domestic water consumption across all villages was just 40 lpcd, less than the JJM benchmark of 55 lpcd for the rural areas. Most villages in northern Karnataka are under water-stressed conditions due to insufficient availability of water, lack of infrastructural development, untapped surface water potential and ineffective governance. This necessitates increased investment by the government to create public infrastructure for augmenting domestic water supply, especially in regions with possibilities of tapping surface water. There also arises a prerequisite to ensure optimum utilisation of surface and groundwater, based on empirical assessments of the availability of water resources across regions, especially in water-stressed and arid regions.

Water security is a major concern in semi-arid regions of the Ballari and Raichur districts. The JJM aims to provide safe and adequate drinking water to all households in rural areas of India. The criticality of implementing the JJM has been demonstrated in this study through the SMLR model, which indicates that the size of the household, tap water connections and landholding of the household (in this order) are the three independent variables which have a statistically significant impact on the per capita domestic water consumption of the households living in the study area.

The outcomes and findings of this study will benefit the rural sector and water resource planners in semi-arid areas of India who are working to fulfil the objectives of the JJM since it will enable the mobilisation of investments required to construct the surface water supply infrastructure like canals and pipelines to enhance domestic water consumption in all villages of the historically backward K–K region to the level of 55 lpcd as per JJM norms.

Besides providing data on current and future projections of water availability and demand strategies in the drought-affected districts of Raichur and Ballari, this study also provides a strong justification for the creation of water supply infrastructure, including the A–P ILR project as per the revised alignment developed by the authors of the present study to minimise the social and environmental impacts of this project as well as the required investments. By providing an adequate quantity of water for irrigation and domestic use, the A–P ILR project will ease the water stress in the rural areas of Raichur and Ballari districts and contribute to food security and income growth of the farmers in these drought-prone areas. Implementation of this project as a part of the JJM will enable the people living in the rural areas of these districts to achieve SDG 6, SDG 2 and several other SDGs.

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The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

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